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Cement-Lime Plaster Mortar with the Addition of Granite Powder as a Material in the Idea of Sustainable Construction

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The granite industry produces a nuisance waste called granite powder. In its bulk state, it poses a threat to people and the environment. The main objective of this article is to determine whether waste granite powder would be safely used in cement-lime plasters. Initially, the best-predicted percentage of the additive in the finished plaster mortar was taken and was in the range of 5-10 %. A reference test was also performed to compare the results. Subsequently, the prepared samples were subjected to test the fresh mix properties and the evaluation of the cured composition. In the final stage, the analysis of the results showed that the 10 % addition of granite powder resulted in a significant improvement in the strength parameters of the mortar. Particularly noteworthy is the improvement in the pull-off strength parameter for silka substrates, which is the superior parameter tested in plasters. In conclusion, it was observed that the addition of waste granite powder improves the mechanical properties of cement-lime plasters. The use of granite powder in the production of cement-lime materials will reduce the amount of material deposited in landfills. It will also reduce the percentage of cement in the mixes, while maintaining the same or even better parameters, leading in the long run to a reduction in CO_2 emissions by the cement industry. This solution is definitely beneficial to the environment and human health, and it is also economical.

1. Introduction

The problem of climate change is now receiving increasing attention. The effect of global warming is now one of the major climate problems. Caring for the environment has become not so much fashionable as necessary and essential to prevent natural disasters. Over the last few decades, there has been a significant increase in greenhouse gas emissions. This is closely related to the rapid industrial evolution.
Carbon dioxide is the gas that increases most dramatically. It is formed during the combustion of fossil fuels. The accumulation of CO_2 in the atmosphere causes the capture of infrared radiation. Radiation is emitted from the earth's surface. The absorption of sunlight leads directly to the heating of our planet.
The continuous trend of increasing the temperature of the surface of water and oceans we call global warming. This progressive phenomenon causes dangerous phenomena. Storms become more powerful, causing flooding. The wind becomes known as a gale or tornado that destroys homes and everything else in its path. Climate warming has also resulted in an increase in the frequency of droughts or heat waves (Gray et al., 2016). Scientists estimate that by 2100, in a climate with four seasons so far, winter will last less than 2 months and summer almost half a year (Wang et al., 2021). The literature (Guan et al., 2021) also points to a major challenge to conservation of biodiversity caused only by climate change. Chan and Wu (2021) indicate that about 5.7 % of the earth's surface has become drier and hotter as a result of anthropogenic activities since 1950. The topic of climate change is not only a media topic, but also an extremely important one. It should be noted that the greatest responsibility lies with large industrial concerns. A single person can naturally contribute to taking care of the environment. However, the scale of the problem exceeds the capabilities of an individual.
From an ecological point of view, the construction sector is one of the most harmful to the environment. The cement industry is responsible for over 25 % of global industrial carbon dioxide emissions (Chen et al. 2022). The same study indicated that global carbon emissions from the cement industry have increased by 186 %, comparing data from 1990 (0.86Gt) with 2019 (2.46Gt). Cement, being a material with high energy requirements,

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as its energy requirement is about 30 GJ/t, is also the most important material. More often, only water is used, which is after all the basis of human existence (Shanks et al., 2019). Cement, thanks to its binding properties, binds all components that are part of concrete, mortar, plaster, or building chemistry products. Researchers (Nasibulin et al., 2009) have pointed out that cement is a key element in any analysis of CO_2 reduction strategies. One of the ways to reduce the role and share of cement in modern construction is to find an equivalent material. This aspiration is also realized by partially replacing cement with another product. Crossin (2015) shows that the addition of ground granulated blast furnace slag can lead to a reduction in greenhouse gases by as much as 47.5 %. Lin et al. (2003) conducted a study on the addition of fly ash slag from municipal waste incinerators as a replacement for cement. They claim that its addition up to 20 % of cement content in mortar, does not deteriorate the quality of the resulting concrete. Du and Dau Pang (2020) also conducted a study on the replacement of cement in concrete with another material - kaolin clay and limestone.
The article (Bica et al., 2009) draws attention to the complexity of the influence of building materials on the environment. Such an analysis should be approached holistically, or the evaluation criteria should be clearly defined. Holistic approach should include system elements such as politics, economy, environment, planning as well as cultural and geographical conditions (Foley et al., 2017). Energy consumption, toxins, resource supply, and the impact of global warming, among others, are some of the elements worth focusing on. When striving for sustainable materials engineering, it is important to remember to use locally occurring materials. This avoids additional CO_2 emissions caused by transportation. The use of waste material, even from an environmentally unfriendly project, also makes it possible to create green material. An object that would often degrade for hundreds of years is then recycled. Life cycle analysis is also important as the longer a building exists, the smaller the impact of energy consumption and pollution contained in its production.
Uri Cihat Onat and Murat Kucukvar (2020) analyzed 155 studies on carbon footprint in the construction industry. They found that most studies analyze the problem at the national (75 %) and city (18 %) levels. The share of studies at the global level, which accounts for 6 % of all published works, is much smaller. The results of their work are presented in Figure 1.

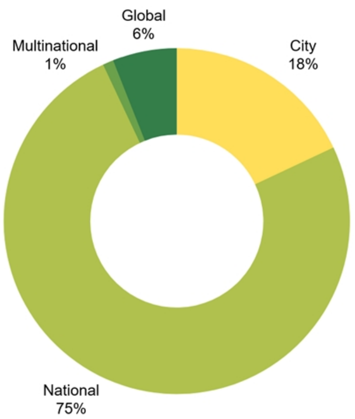

Figure 1: Classification of scientific research by area included

The popularity of national-level surveys is related in part to the availability of data, but also to the sense of real impact on the immediate environment.
In an effort to create eco-friendly building materials, attempts are being made to replace the cement component. Additives in the form of fly ash are already known and widely used. Coconut or polypropylene fibers are gaining popularity. The use of local, easily available materials is noticeable. In this paper, the influence of granite powder additive, which is a waste material, will be described. The disposal of this product is a serious problem, as the powder is a non-biodegradable industrial waste. The filling properties of granite powder have already been reported in the literature by researchers Arivumangai and Felixkala (2014) and Gupta and Vyas (2018) among others. The objective of this study was to evaluate the effect of granite flour on the mechanical properties of cement-lime plaster mortar and to present it as a material compatible with the idea of sustainable construction. For this purpose, the basic parameters of both fresh and hardened mortar with the addition of granite powder in different amounts were determined. To allow a correct interpretation of the data obtained, a reference test without any modifications was also carried out. Granite powder was added at 5, 7.5, and 10 % by weight of the dry mass of the finished mortar. The results obtained clearly show that the addition of waste granite powder to the plaster mortar makes it possible to reduce the amount of cement used, leading to an environmentally friendly material.

2. The idea of sustainable engineering in construction materials on the example of plaster with granite powder

The concept of sustainable construction indicates the need to consider ecological, economic, and social aspects when evaluating the subject of analysis. The key objective is to reduce the amount of waste, energy consumption, and natural resources. If possible, it is recommended to reduce the costs of building construction and operation by finding environmentally friendly solutions.
Building materials containing locally occurring materials, such as rock flour, fit perfectly into the trend described above. Figure 2 shows the location of granite and limestone mines on the Poland map. It should be noted that the deposits are mainly located in the south-west part of the country.

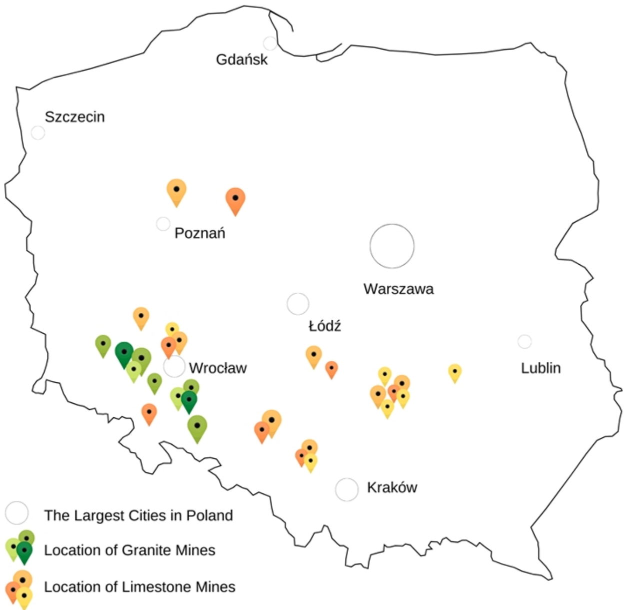

Figure 2: Locations of mines for minerals used in modified building materials

The use of local raw materials reduces transport costs and, most importantly, reduces the amount of carbon dioxide released into the atmosphere. This part of the article presents the results obtained for the composite material, which is cement-lime plaster with the addition of granite powder.

2.1 Granite

The local material used was obtained by processing granite. Granite is a rock contains 80 - 100 % by volume of major materials such as quartz and feldspars, and 0 - 20 % by volume of accessory materials. Granite is a rock characterized by ease of processing as well as high strength and acid resistance. It is during grinding and cutting of granite rocks that granite powder (Figure 3) is created. It is a troublesome waste due to its fine form.

Figure 3: Waste granite powder

The granite powder used in this research comes from Strzegom located approximately 60 km from Wrocław. One type of this additive was used. Its bulk density is 1,194 kg/m^3. The particle size distribution of the additive was determined using sieve analysis in accordance with PN-EN 933-1:2012.

2.2 Methods

Investigations describing the influence of granite powder on the properties of cement-lime plaster were carried out in the laboratory of the Wrocław University of Technology in accordance with the binding standards. Parameters such as compressive strength, bending tensile strength, absorption and adhesion of the mortar were tested. The adhesion force between the modified mortar and the substrate was tested according to PN-EN 1015-12:2016-08E. This test determines the maximum adhesion force between two materials. Compressive strength and tensile strength were determined according to PN-EN 196-1 and PN-EN 1015-11. The hardened mortar was tested in a test press after 28 days of curing in wet conditions. Testing the value of water absorption coefficient, conducted in accordance with PN-EN 1015-18:2022E, consists in reading the mass of a sample placed in a cuvette with water, after 10 and 90 minutes of soaking. The sample must first be dried to a constant mass. The absorption coefficient is calculated from the formula:

$$C = 0.1 * (M2 - M1)\ \left[\frac{kg}{m^2 * min^{0.5}}\right] \tag{1}$$

The M1 value describes the weight of the sample after 10 minutes of soaking in water. The M2 number is the weight of the same sample, weighed after 90 minutes. Both values should be given in grams.

2.3 Results

The results obtained clearly showed that the addition of 10 % granite waste powder has a positive effect on the mechanical properties of cement-lime plaster mortar. Obtaining the best possible parameters is extremely important from the point of view of the object user. As a result, they make it possible to reduce building operating costs. In plasters, the value of peel strength is crucial.

The substrates, for the pull-off test, were selected because of their frequent use in the construction market. A Silka brick of class 15, a TERMOton P+W clay brick of class 15, and a solid brick differ considerably in their porosity. This results in different values of absorbability of the bases. For the ceramic hollow brick this value is about 18 %, and for the silka brick about 14 %. The highest value of water absorption occurs for solid bricks and equals 22 %. The obtained results, obtained by the pull-off method, are shown in Figure 4. It shows the relationship of mortar adhesion values after 28 days, on three types of substrates, obtained for different amounts of granite powder added.

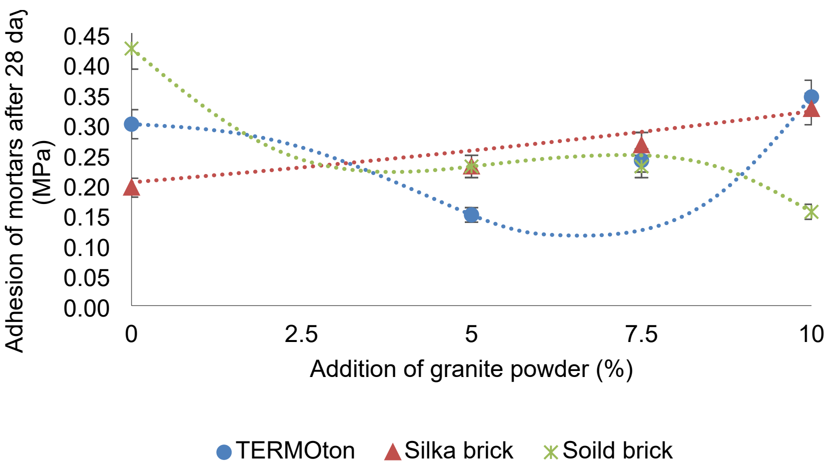

Figure 4: Change in the adhesion of hardened mortars to the substrate with respect to the type of substrate and the amount of granite powder added

On the solid brick substrate, there was a continuous decrease in peel strength as the amount of granite powder added increased. Hardened cement-lime plaster mortar on the TERMOton substrate and on Silka brick behaved quite differently. The adhesion of the hardened mortar in TERMOton at 5 % by weight of the dry mix decreased drastically and then increased as the amount of granite powder added increased. An increase of 15 % over the reference sample was obtained for a 10 % addition. The most spectacular improvement in adhesion properties was observed for Silka brick, where the adhesion value increased with an increasing amount of granite powder added. The tested value reached 166.67 % of the value of the reference sample with 10 % addition. These results indicate the potential to use modified mortar on two of the three substrates tested.

Cement-lime plaster can be used both indoors and outdoors. Due to which it is exposed to weather conditions such as snow and rain. Therefore, another extremely important parameter from the point of view of use is the value of water absorption coefficient. In the harmonized standard, it currently appears as the only property determining the resistance of the tested material to moisture.
For cement-lime mortar, the calculated coefficient should be between 0.6 and 1.9 (kg/(m^2 * min$^{0.5}$)) depending on the mortar variety. The values of the water absorption coefficient obtained are shown in Table 1.

Table 1. Value of the Water Absorption Coefficient

Series of Mixes [-]	Water Absorption Coefficient (kg/(m^3 * min^{0,5}))
Ref	0.640
5 %	0.631
7.5 %	0.591
10 %	0.560

It should be noted that as the amount of granite powder added increases, the value of this coefficient decreases. This is understandable since this additive has filling properties, resulting in an increase in the packing density of the mortar. This leads to a decrease in capillary rise of water. The more additives used in the mortar tested, the higher the sample mass. The mortar had a more compact form. Here, the relationship between the moisture resistance property of the tested material and its bulk density is clearly visible. Similar correlations were observed for the compressive and bending tensile strength testing (Figure 5).

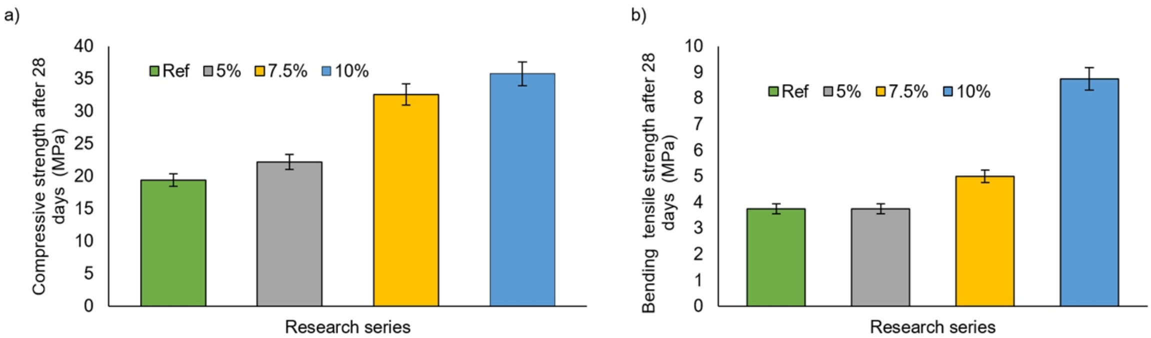

Figure 5: Strength test: a) compressive strength after 28 days (MPa), b) bending strength after 28 days (MPa)

The highest value in the parameters studied was obtained for 10 % granite powder addition. The values obtained are consistent with the study of (Jankowska-Renkas, 2010), which reports an increase in compressive strength after modification of concrete with chemical admixture and granite powder. However, the results obtained for the plaster mortar are more spectacular.

3. Conclusions

Cement-lime plaster mortar with granite powder waste perfectly fits into the idea of ecological construction. It consists in setting standards based on elements which are the least harmful to the environment throughout the life cycle of a building. The use of materials complying with this idea allows for an ecological approach to construction already at the stage of choosing building materials. The use of natural waste materials available locally allows reducing CO_2 emission, which arises during transportation of raw materials. A very important aspect is the reported positive effect of granite powder addition on the mechanical, adhesive and absorption properties of cement-lime plaster mortar. The addition of waste material in the amount of 10 % by weight of dry mix of plaster mortar gives the best results of the study. It was found that::

- The volume density of the fresh mortar increased with the amount of granite powder added.
- The addition of granite powder at 10 % significantly improved the mechanical properties of the hardened mortar. The compressive strength increased by 84.33 % compared to the reference sample, and the bending tensile strength increased by 133.33 %.
- The adhesion of cement-lime mortar to the TERMOton substrate decreased by additional amounts of 5 % and 7.5 % compared to the reference mortar. However, the addition of 10 % granite powder improved the adhesion properties of the mortar by 15 % over the unmodified mix.

- When plastering on solid brick ceramic substrates, a continuous decrease in mortar adhesion to masonry was observed. Therefore, the use of granite powder additive in cement-lime mortar on this substrate is not recommended.
- The most recommended substrate is Silka brick. The adhesion value increased as the amount of granite powder added to the dry cement-lime mixture increased. It reached 166.67 % of the reference value of the sample with 10 % addition of granite powder.

The results obtained make it possible to reduce the amount of basic binder, thus reducing the cost of obtaining a finished cement-lime mortar with further improved properties. The use of granite powder waste to produce cement-lime materials on a large scale will begin to reduce the amount of material in landfills, thus contributing to solving the problem of landfilling this by-product. Such a solution is definitely beneficial for both the environment and for economic reasons. The design of sustainable building materials is essential from an environmental perspective.

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